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A Simple Antenna Design of Implantable RFID based on EFAB Technology

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Abstract— This paper is to present a new technology for implantable RFID antenna design. As implantable RFID are popularly used as active devices for animal identification, bio-medical sensor etc. Size miniature and high working efficiency are the basic requirements for these implantable devices which cause no discomforts for a body. A new MEMS process called EFAB is introduced. The implantable RFID antenna design is based on the use of micro-coil. With EFAB design rules and parameters, the simulation results have shown that we can satisfy the requirements of implantable RFID antenna.

1. INTRODUCTION

As the development of the micro-electronics and wireless communication technologies, the Radio Frequency Identification (RFID) [1–6] is getting mature and is widely used in different areas, especially indoor monitoring system, logistic management system and one- card-for-all payment system. Besides, for those bio-medical electronic devices that have to be implanted inside the human or animal bodies such as nervous muscular stimulators, implanted hearing aid devices etc. [7–13], they need to use passive RFID technology to achieve wireless transferring electronic signals and power. With integrating of the RFID and sensing devices, we can develop an implantable bio-medical device that can be used as an identification and physiology monitoring. On the other hand, for those RFID implanted sensing device which can obtain non-stopping energy supply without using battery or power source. Recently, the implantable RFID technology is a hot topic for researchers to work hard.

Differing than those current mature consumer RFID technologies, in order to make the RFID device to satisfy the requirements to implant devices into human or animal bodies, especially it has to satisfy the safety standards for the RFID EMC and the miniature size constraint for an implanted device. Not only to consider the absorption effects of the transmission and reception of electro-magnetic waves for animals also side-effects which hurt an animal when a device is implanted into its body. For this reason, the size of the device has to be as small as possible in order to reduce the influencing effects caused by the implanted device [14]. In addition, the device has to be communicated with the outside world within a workable distance. It is obvious that the antenna design of the RFID device is very important

This paper is trying to introduce an antenna design with a multi-layer MEMS based on EFAB technology [15]. Based on the requirements of implanted antenna, computer simulations have been done in order to design the RFID device antenna structure.

2. THE DESIGN REQUIREMENTS OF IMPLANTED RFID

RFID uses wireless communication technologies to achieve the data exchange between IC card and system [1]. For those international standards, such as ISO10536, ISO14443, ISO15693, ISO18000, they are working on ISM band at 135 kHz, 13.56 MHz, 433 MHz, 915 MHz and 2.45 GHz respectively. For the devices to be implanted into an animal body, we have to consider effects due to the absorption of electromagnetic wave by the organs and how it influencing to the health conditions and activities of these organs. For this reason, we intend to avoid loss or absorption of EM wave inside the body of an animal. In normal condition, the EM wave inside the animal body, the rate of attenuation or absorption of EM wave is proportional to the square root of the transmit frequency [16]. Hence, the frequencies of implanted RFID is preferable to be chosen at lower frequency bands, however, this will need a larger inductive coupling antenna. Of course, it is illogical or impracticable for an implanted device with a too big size. In this case, the working frequency for an implanted RFID is chosen at 13.56 MHz.

Lots of international companies have developed of 13.56 MHz RFID chip-products, such like, Siemens, Sony, Philips, Atmel etc. recently, the built-in capacitance of these RFID chips is in

the range of $100 \sim 200$ pF and the external inductance needed is greater than 689 nH. (if built-in capacitance of 200 pF is assumed). For normal RFID cards, if the printed circuit technology is used and it is easy to achieve the inductance value by using a large antenna coil. However, for an implanted application, we need the size of the antenna has to be small, so we decide to use MEMS technology [17] to minimize the antenna size. There are a lot of design methods for the antenna coil [18–22], although there are differences in formulating methods for calculating the inductance value, on the whole, the inductance value of the antenna coil design is closely related to several parameters of the antenna structure, for instance, the number of turns, radius, line width and the separation between turns of an antenna coil. Therefore, this paper will base on these parameters mentioned above to design the implanted RFID antenna.

It is mainly through the coupling EM field of body antenna to the system antenna in order to perform the wireless data exchange for the implanted RFID of an animal. The performance of the data communication mainly depends on the energy coupling transmission efficiency (η_{12}) between the inside-body antenna and the outside-system antenna. The η_{12} can be represented as shown in Equation (1) [23]:

$$\eta_{12} = \frac{1}{1 + \frac{1}{k^2 Q_1 Q_2}} \quad (1)$$

where Q_1 and Q_2 are the quality factor of transmitting and receiving antenna respectively, k is magnetic induction coupling coefficient.

$$k = \frac{M_{ab}}{\sqrt{L_a L_b}} \quad (2)$$

where M_{ab} is the mutual inductance coefficient, L_a and L_b are the inductance values of two antennas respectively.

It is obvious, the larger the Q factor and coupling coefficient k of the antenna, the efficiency of the antenna power will be better and the communication quality will be higher.

In this case, when the system frequency and the built-in capacitance of the RFID chip are well defined, then the inductance value L of the antenna coil will be fixed as well. For the mutual inductance coefficient M , it is mainly related to the positions of the transmitting and receiving antennas and the coefficient is depending on the antenna directions. Usually the transmitting and the receiving antenna coils are in the same axis will have a larger mutual inductance coefficient and the closer of the two antenna positions, the coupling coefficient will be larger. Therefore, our implantable RFID antenna design is mainly paying attention only to the antenna inductance value L to be chosen and also how to increase the Q factor of the antenna.

Of course, the power coupling coefficient between antennas is related to the implanted device position, depth and organization of the animal. It will change according to the EM wave power absorption of the body of a creature (SAR, Specific Absorption Rate) [16, 24, 25]. In this paper, we shall not discuss the problem due to the coupling coefficient of RFID inside body. It is our future work and detail analysis will be done in the future.

3. ANTENNA DESIGN BASED ON EFAB TECHNOLOGY

The miniature RF antenna is made by using the MEMS planar technology on the silicon substrate [26–28]. The antenna made by the planar technology has a disadvantage of using large silicon area and contacts to the silicon substrate will be occurred, hence the loss is high and will have a smaller Q value. The miniature of RFID antenna could not achieved with these conditions. If we adopt multilayer technology for antenna coils, less area are needed and also we can avoid contacts to the substrate, this will cause less loss hence the antenna Q factor will be increased. In this case, a new kind of MEMS technology-EFAB [15] is introduced for implanted RFID antenna design.

3.1. EFAB Technology

EFAB technology is an additive micro-fabrication process based on multi-layer selective electro-deposition of metals (MEMS technology). The process is designed to help rapidly form multiple independently-patterned metal layers on top of one another. This enables designers to create intricate 3D geometries with micron-level precision. EFAB is a batch process like semiconductor manufacturing in which many devices are built simultaneously on wafers, allowing volume production at low cost. The essence of this approach is a basic three-step process that is used to generate

each layer. This repeats as many times as there are layers to build the desired complex devices. The complete flow of the EFAB technology [29] is shown in Figure 1. These steps are: (a) Patterned layer deposition; (b) Blanket layer deposition and (c) Planarization. (d) After planarization of the layer, this layer may serve as the new substrate, allowing the process cycle ('a' through 'c') repeats until the full desired height of the device is achieved; (e) Finally, after all layers are completed, a release etchant removes the sacrificial metal, leaving behind the free standing device.

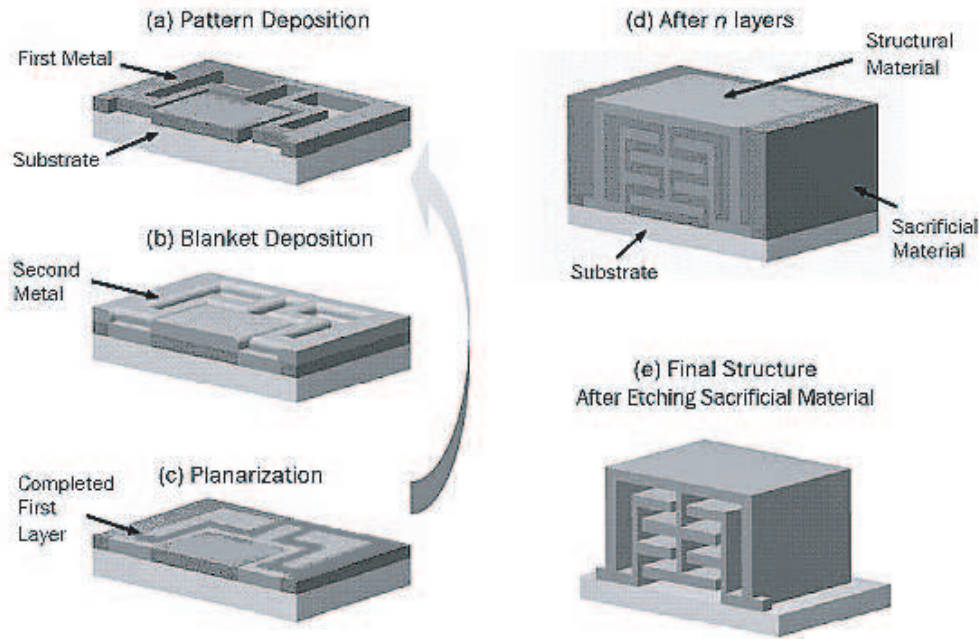


Figure 1: EFAB technology process [21].

EFAB technology at the moment can provide thickness of each layer from 2–10 μm and it can make devices up to 20 layers or more. Multilayer structure can make device harder and bigger than the MEMS technology. EFAB technology can choose any metal which can be metal plated or alloys (for example, nickel, copper, silver, gold or nickel cobalt metal alloy etc.) to build the structure of the device, but there is a constraint condition, that is, the metal structure must not be affected after etching sacrificial material.

3.2. The Miniature Coil Antenna Design Method

SolidWorks is a kind of 3D graphical EDA tool and SolidWorks uses 3D mechanical design software to design and manufacture MEMS and microdevices as part of a single solution. SolidWorks software is the recommended design software for EFAB Access and enables viewing of 3D micro geometry as it will appear when fabricated in layers and the structure data file [29]. ANSOFT HFSS is an EM field analysis software tool which can output compatible SolidWorks data file format. These two software tools are used for the antenna coil miniature design in this paper.

For a dedicated area of chip size of the antenna, it can acquire the inductance value of the antenna coil by increasing the coil layers. Firstly, the single layer coil structure has to be well defined. This layer diagram is shown in Figure 2 and the top view and the cross-section layer of this layer have been shown in Figure 2(a) and (b) respectively. Among them, the line width of coil (w), the separation between strip lines (s) and the thickness of line (h). The antenna adopts nickel-cobalt (the electrical resistivity $10.5 \mu\Omega\text{-cm}$) material, the substrate is using alumina (the electrical resistivity is $10^{14} \Omega\text{s-cm}$, relative permeability is 9.9), among them, the choice of material of the antenna is providing by EFAB technology related factory [29]. The port 1 and port 2 in Figure 2(a) are the input and output ports of the antenna respectively, The calculation method of the parameters S and the admittance Y_{11} based on the two-port network [30], we can obtain the antenna value L and Q .

$$L = \text{Im}(1/Y_{11})/2\pi f \quad (3)$$

$$Q = \text{Im}(1/Y_{11})/\text{Re}(1/Y_{11}) \quad (4)$$

From the equations above, admittance parameter Y_{11} is converted from the two-port network parameter S , f is the working frequency of the antenna coil.

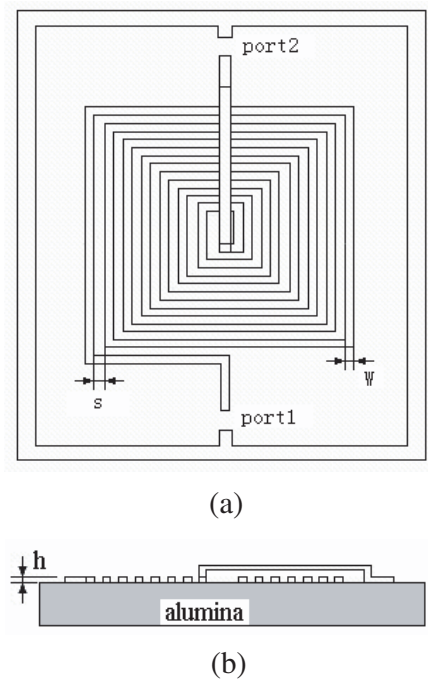


Figure 2: Configuration of the inductive coil antenna. (a) Top view diagram, (b) Cross-section diagram.

According to Equations (3) and (4), for a fixed antenna structure and a single layer antenna coil, the simulation analysis is carrying out. Firstly, the changing of the inductance values and Q values are being observed, hence the structure parameters (coil number, strip line width and strip line separations) are being fixed. After that, for two layer antenna coils, the changing of the inductance and Q values will be investigated when the separations (distances) of the layers are changing. For this we can find out the optimized separation for the two layer coils. Finally, we will obtain the decided inductance values by increasing the numbers of the coil layer.

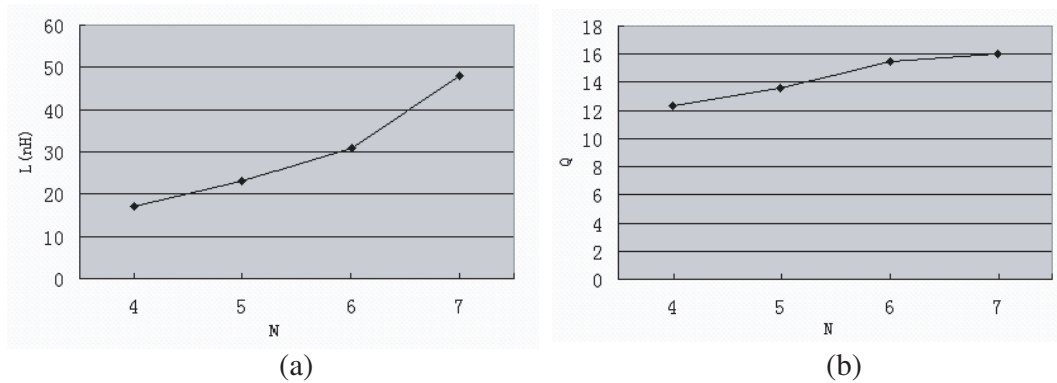


Figure 3: Inductance (L) and quality factor (Q) vs coil turn (N). (a) N vs L , (b) N vs Q .

4. DESIGN BY COMPUTER SIMULATION

We have to do analysis on the number (N) of turns of the first layer inductive coil. As shown in Figure 3, the numbers (N) of turns of the inductive coil are: 4, 5, 6 and 7 respectively. It shows the corresponding inductance values (L) at the dedicated frequency of the coil for Q is the maximum. The design for other parameters ($w = 50 \mu\text{m}$, $s = 50 \mu\text{m}$, $h = 10 \mu\text{m}$) of the coil are based on the data provided by EFAB for minimal size for the first layer. In Figure 3, it shows that as the number of turns of the coil increased, the values of the inductance L and Q factor are also increased. For

this reason, the decided inductance value can be obtained through the increment of the number of turns of the coil. However this will increase the area size of the coil. As shown in Figure 3(b), when the number turns of coil has increased from 6 to 7, but it has found that Q value has insignificantly increased. Hence, for a chosen area size of silicon, since we can choose the maximum number of turns of coil but we have to consider the change of Q value. As we can see Q value is close to constant after the number of turns reaches certain value.

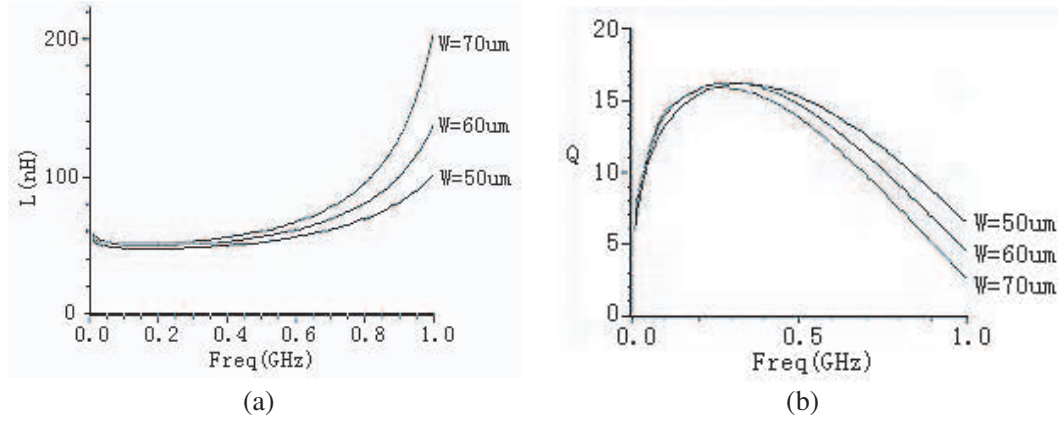


Figure 4: L and Q vs frequency with different strip width (w). (a) Freq. vs L , (b) Freq. vs Q .

Following the number of turns of coil has fixed as $N = 7$, and other parameter are set to be $s = 50 \mu\text{m}$, $h = 10 \mu\text{m}$. The strip width is changing respectively with $50 \mu\text{m}$, $60 \mu\text{m}$ and $70 \mu\text{m}$. Computer simulations for the structure of the antenna coil are being done. The results as shown in Figure 4, although the maximum value of Q is basically unchanged, as the frequency has been increased, the wider of the strip width will cause the Q value drops faster. L increases as the strip width w increases, but not much change when the Q is the maximum. The inductance values for maximum Q are 48 nH, 50 nH and 53 nH respectively for w equals $50 \mu\text{m}$, $60 \mu\text{m}$ and $70 \mu\text{m}$ respectively. As shown in Figure 3 and 4, the influence of the number of turns of the coil to the value of inductance of the antenna coil is greater than the changing of width of the strip. Therefore, in the design, usually we mainly reduce the width of the strip and increase the number of turns of the coil.



Figure 5: Cross-section view of two-layered configuration.

According to the above analysis and the required area of the antenna is $1500 \times 1500 \mu\text{m}^2$. Then you can obtain parameters of the first layer inductive coil as: $N = 7$, $w = 50 \mu\text{m}$, $s = 50 \mu\text{m}$, $h = 10 \mu\text{m}$. One more layer will be added on top of the first layer and the coil of the new layer will use the same parameters of the first layer. The cross-section of the two-layer structure is shown in Figure 5. The separation of the two coil layers is t . When t has the value of $10 \mu\text{m}$, $20 \mu\text{m}$ and $30 \mu\text{m}$ respectively, the coil inductance value L and Q value are shown in Figure 6. When the t become larger, the Q value is increasing as well but the L value is reducing in the corresponding frequency point. Compare with Figures 4 and 6, that is to compare a single layer coil and a double layer coil, as the number of layer increased, it increases the inductance value L and also the Q value. The effect of increase the number of layers is much better than simply increase the value of t . Therefore we set $t = 10 \mu\text{m}$ and then increase the number of layers to get a high value of L .

Summarize the analytical results above, the final setting for the parameters of the turns of the coil as: $N = 7$, $w = 50 \mu\text{m}$, $s = 50 \mu\text{m}$, $h = 10 \mu\text{m}$, $t = 10 \mu\text{m}$. Totally it is the 4-layer coil structure, as shown in Figure 7. Its physical volume on the whole is: $1500 \times 1500 \times 70 \mu\text{m}^3$. The computer simulation has shown the inductance value of the coil as $L = 702 \text{ nH}$ and $Q = 18$. These values can meet the specification requirement of the RFID system for real applications.

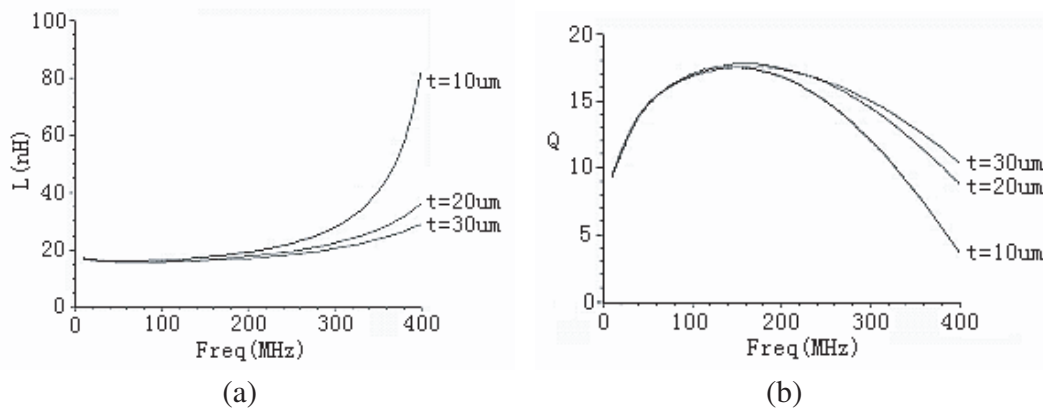


Figure 6: L and Q vs frequency with various separations between the two-layer coil. (a) Freq. vs L , (b) Freq. vs Q .



Figure 7: Cross-section view of a four-layered configuration.

5. CONCLUSION

In the future, it is a trend for implanted RFID technology for widely used as for animal identification. It will be used as wireless monitoring, physiology function assistance etc. However, antenna design is the major issue of the implanted RFID applications. For those biological electronic medical treatment devices implanted into the human body, it has to be physically relatively small and the power efficiency has to be high in order to transmit and receive data wirelessly. We use EFAB to design the four layer antenna coil which is mentioned above and has a size of $1.5 \times 1.5 \times 0.07 \text{ mm}^3$. Its inductance is 702 nH and the Q is 18. This fulfill the specification requirement for 13.56 MHz band RFID and can be used by most of the chip set produced by RFID micro-electronics in the 13.56 MHz band. For this reason, the design can be used for the need of the implanted device satisfactory.

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